He diffusion in and (U-Th)/He dating of fossil tooth enamel and conodonts

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Fossil biogenic apatite, including bone, teeth, fish scales, and conodonts, is abundant in many sedimentary rocks and often contains ~10^1-10^2 ppm of U and Th. Several previous studies, however, have found biogenic apatite He dating unpromising because of apparently large He "loss" (rather than post-diagenetic U-Th mobility). We measured ages and He diffusion in conodonts and fossil tooth enamel from a variety of settings. Both types of biogenic apatite are characterized by nm- to μm-scale crystallite or prism microstructures. He diffusion experiments in both suggest activation energies similar to Durango apatite (28-31 kcal/mol), but conodonts and tooth enamel show Arrhenius trends consistent with diffusion domain sizes (a) on the order of 10^1-10^2 μm, and 10^{-1}-10^0 μm, respectively. Apparent closure temperatures (assuming dT/dt = 10 °C/Myr) are 58-67 °C for conodonts, and ~10-25 °C for enamel. Deviations from simple Arrhenius trends in conodonts are also consistent with diffusive rounding of He profiles on the whole grain scale.

Conodonts from two localities in Helena Canyon, Colorado and Tempiute Mtn., Nevada yield relatively reproducible He cooling ages [57.5 ± 1.9 Ma (2σ, n=6) and 5.81 ± 0.56 Ma (2σ, n=8), consistent with regional thermochronology and a low closure temperature (<~100 °C). However, conodonts from several other localities yield much more scattered ages, though still broadly consistent with regional cooling histories; preliminary evidence suggests that acid dissolution of host rocks may affect U-Th, and/or He contents of conodonts.

Fossil tooth enamel from Miocene and Pliocene bovids and proboscideans have He ages ranging from 90 ka to 1.6 Ma. Multiple replicate analyses of fragments from individual specimens show much more restricted ranges and consistent regional differences. Three samples from the Siwaliks (mean ann. T ~20-25 °C) have age ranges of 250-330 ka, 440-510 ka, and 90-240 ka, whereas two samples from Nebraska (mean ann. T ~7-11 °C) have age ranges of 1.0-1.2 Ma and 1.0-1.6 Ma. Tooth enamel He ages can be understood by equilibrium production-diffusion of He in microstructural domains on the order of 0.1-1.0 μm. Equilibrium "ages" depend only on diffusion kinetics, domain size (a), and temperature. Using values for the former two from diffusion experiments, the ~2-8x "age" difference between Siwalik and Nebraska samples can be explained by long-term temperature differences of ~6-12 °C. If diffusion kinetics and domain sizes (which appear to correspond to enamel prisms, not crystallites), can be well-constrained, He dating of tooth enamel may provide an useful paleothermometer.

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